Update on ν_e Appearance Background Study for BNL VLBL

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Contents

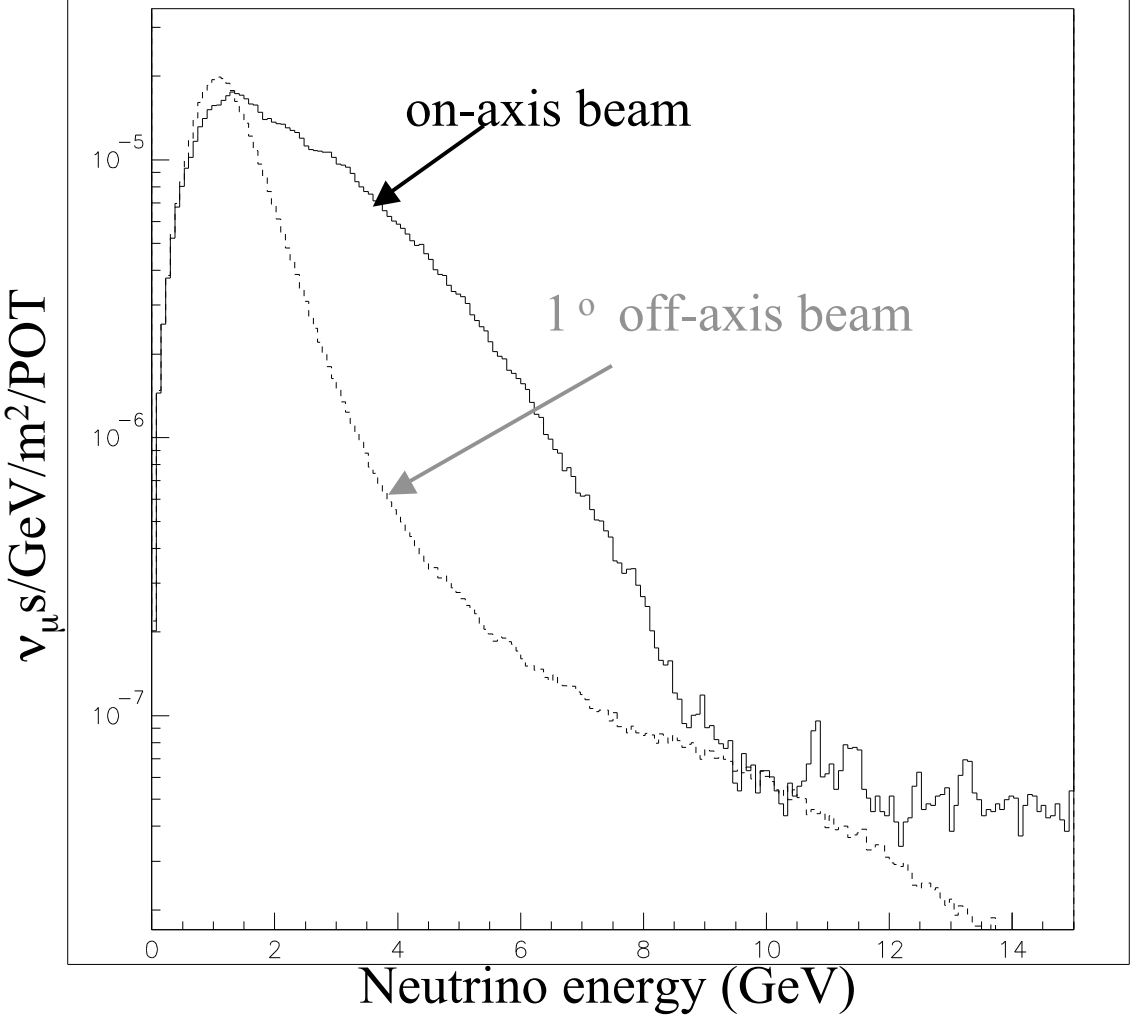
Introduction

- Purpose of this study:
  - Access possibility of observation of $\nu_\mu \rightarrow \nu_e$ and measurements of $\sin^2\theta_{13}$ and δ_{CP} using BNL VLBL beam and UNO
- What have been done:
  - Initial cut:
    - One and only one electron like ring with energy greater than 100 MeV
  - Likelihood analysis using the following variables:
    - pi0-likelihood, e-likelihood, energy fraction, costh, pi0mass
- What's new?:
  - Initial neutrino energy flatter before introducing VLBL spectrum
  - Introduction of new variables
  - Define likelihood as a function of reconstructed neutrino energy

BNL Superbeam

- Spectra of on- and off-axis beams

PRD68 (2003) 12002; private communication w/ M.Diwan



Monte Carlo Event Generation

- Atmospheric neutrino events in SK-> BNL superbeam

  - **All ν interactions available**
  - **SK- I geometry/configuration/PMT coverage**
  - **Standard SK-I analysis package** + Special π^0 finder (ntuples)

Always finds 2nd γ whether it's real or not

Signal : single electron events, Background : NC π^0 with one γ detected + beam ν_e
It's very important to find the undetected γ (2nd ring) from a π^0

  - **Neutrino spectrum reweighted for BNL superbeam using all events**
  - **Total number of events normalized with that expected for BNL using QE events (0.5 Mtons, 5 yr running at 2,540 km)**
  - **$\Delta m^2_{21} = 7.3 \times 10^{-5}$ eV^2, $\Delta m^2_{31} = 2.5 \times 10^{-3}$eV^2**
  - **$\sin^2 2\theta_{ij}(12,23,13) = 0.86/1.0/0.04$, $\delta_{CP} = +45,+135,-45,-135^o$**

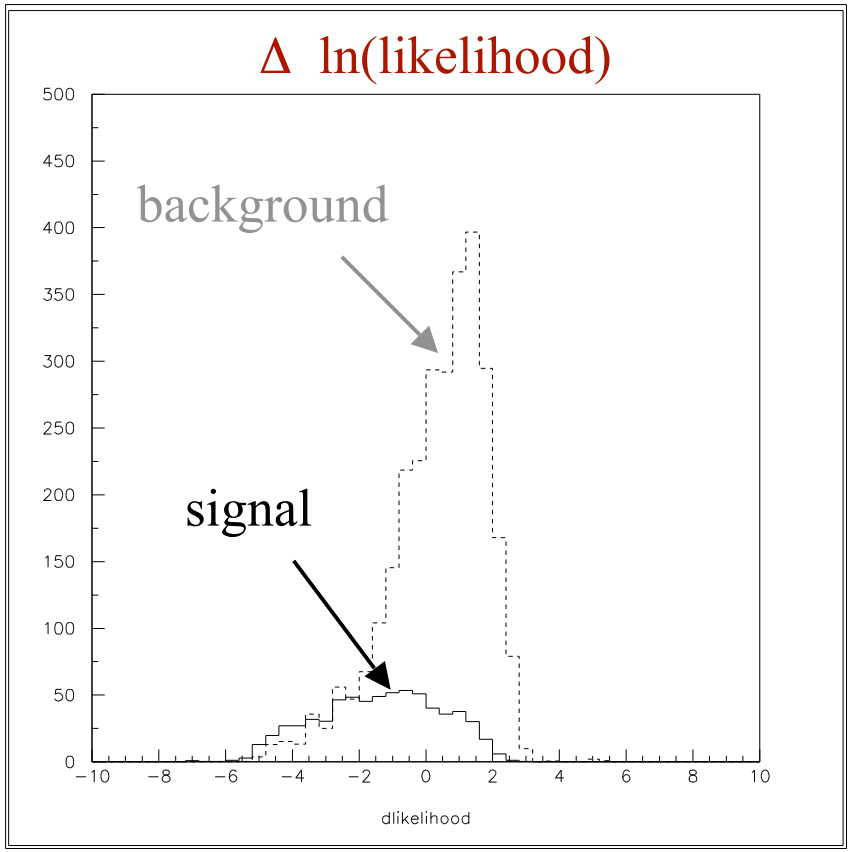
Probability tables from Brett Viren of BNL

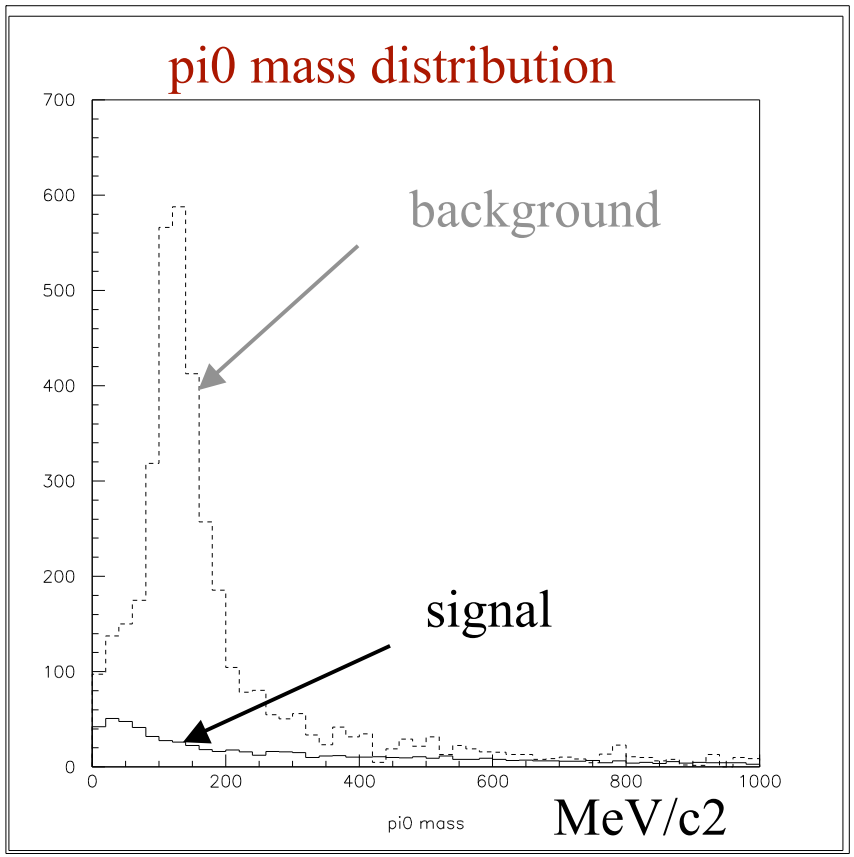
In addition to single electron requirement a cut on difference in a likelihood is used.

_Δ likelihood

ln[likelihood(sig)]-ln[likelihood(bkg)]

- Define likelihood using fraction of 2nd γ energy, cosθ of 1st ring, π^0-likelihood, pid, and π^0 mass . But…





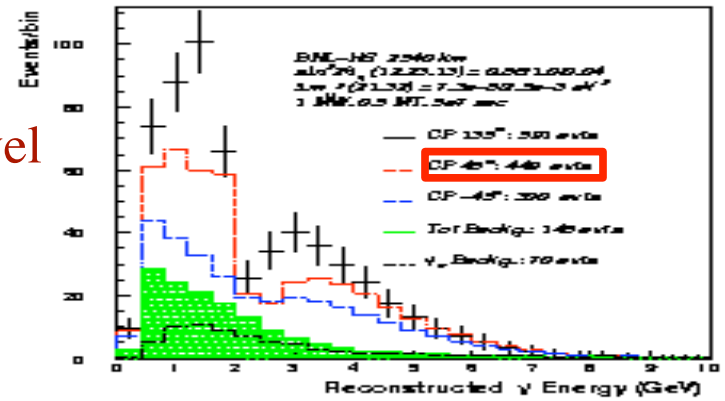
Singnal and Background

ν_e QE for signal, all ν_μ and ν_e NC π^0 for bkg

- BNL report

- **Number of signal and background events**

Based on 4-vector level MC



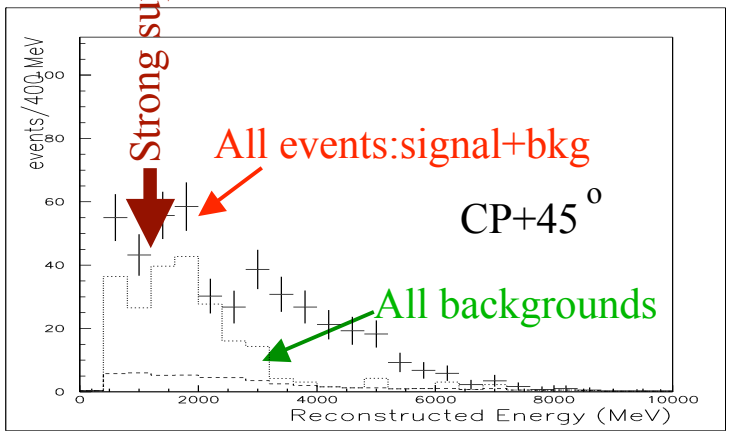
E_{rec}

Signal 303 events

All bkgs 146
(76 from π^0)
(70 from ν_e)

- My previous study

Strong suppression



E_{rec}

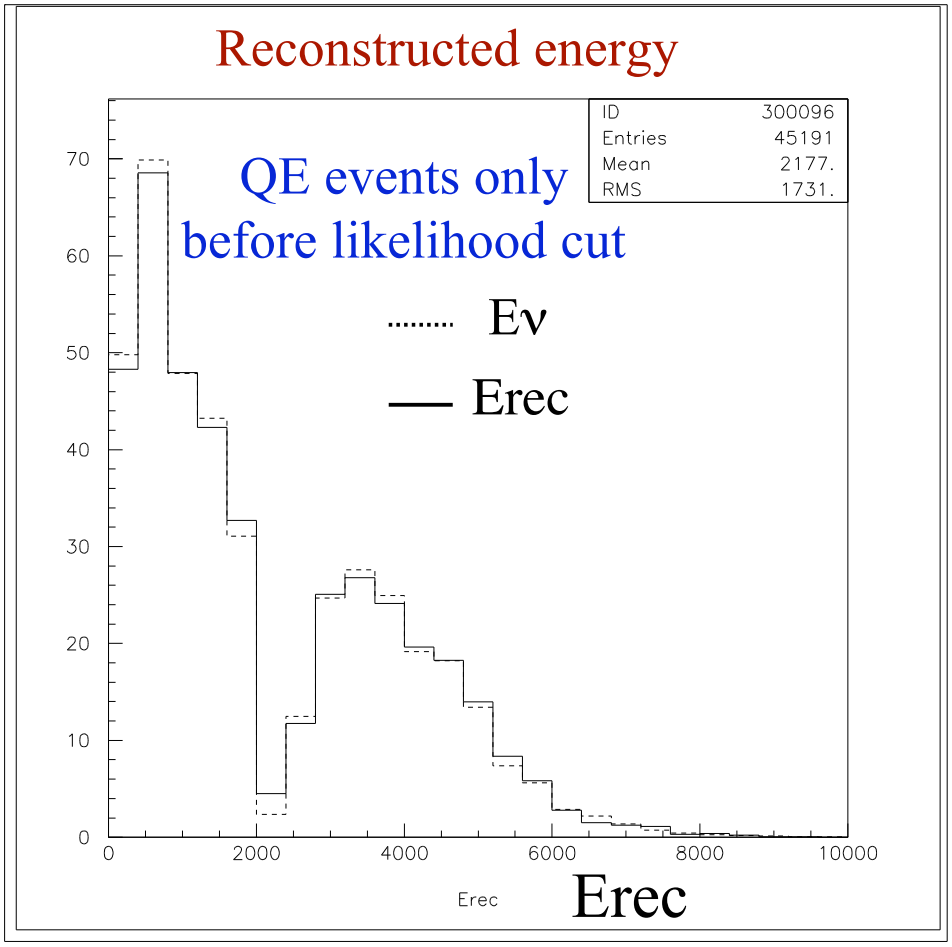
Compare ..... with +

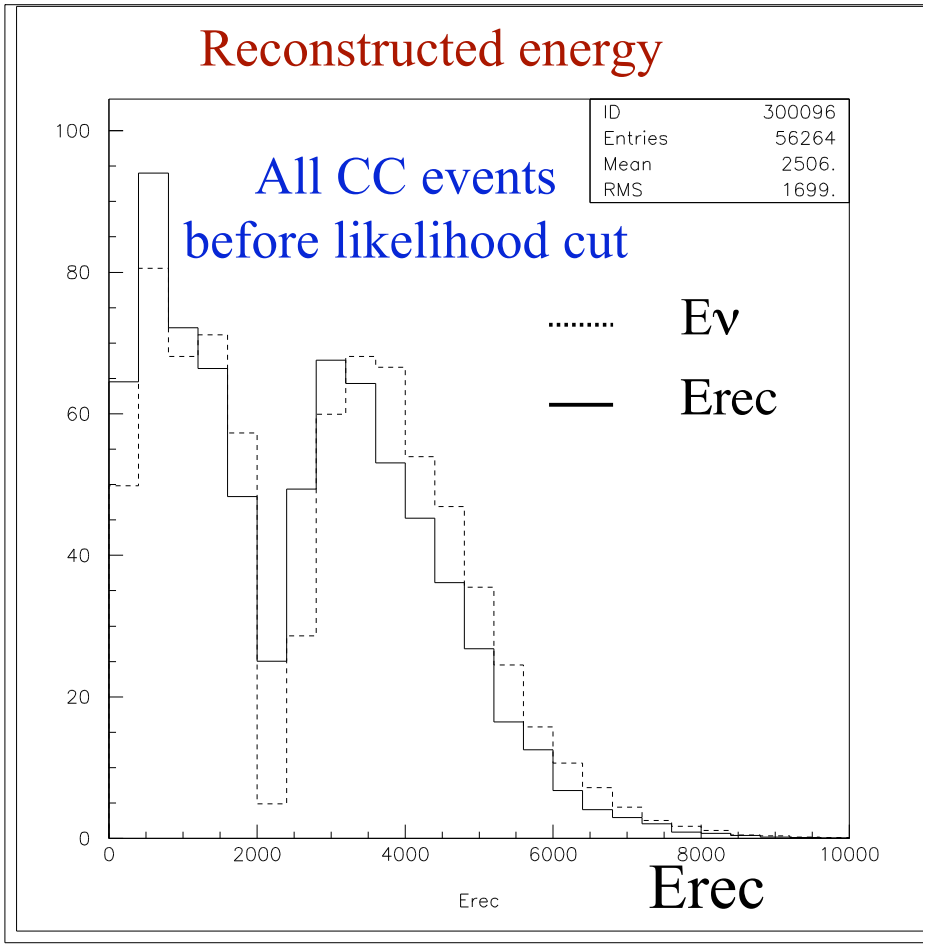
Signal 228 events

All bkgs 233
(180 from π^0)
(53 from ν_e)

What is signal?

- **What is signal and what is background?**





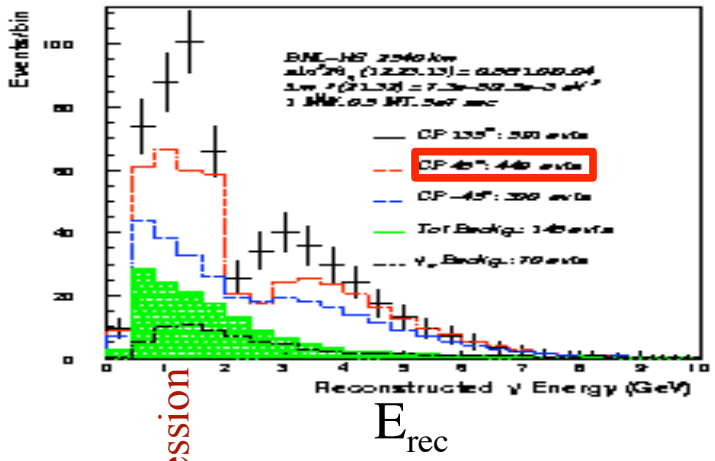
Why not accept all CC events as signals?

Singnal and Background

All ν_e CC for signal, all ν_μ and ν_e NC for bkg
all ν_μ CC for bkg

- BNL report

- **Number of signal and background events**



E_{rec}

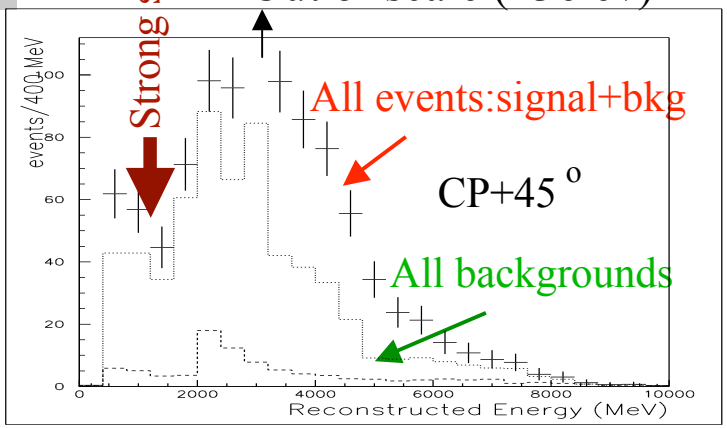
Signal 303 events

All bkgs 146
(76 from π^0)
(70 from ν_e)

- Previous study

Strong suppression

Out of scale (136 ev)



E_{rec}

Compare ····· with +

Signal 397 events

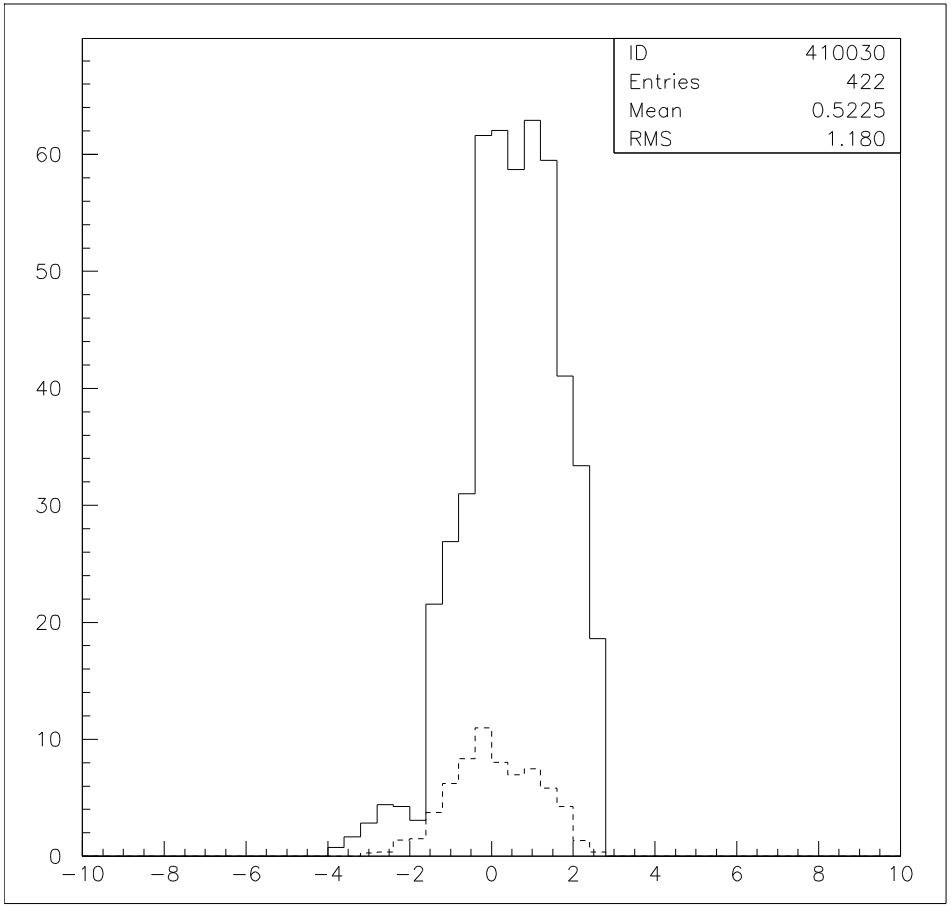
All bkgs 617
(527 from π^0+others)
(90 from ν_e)

Δlikelihood<-0.8

Improvements?

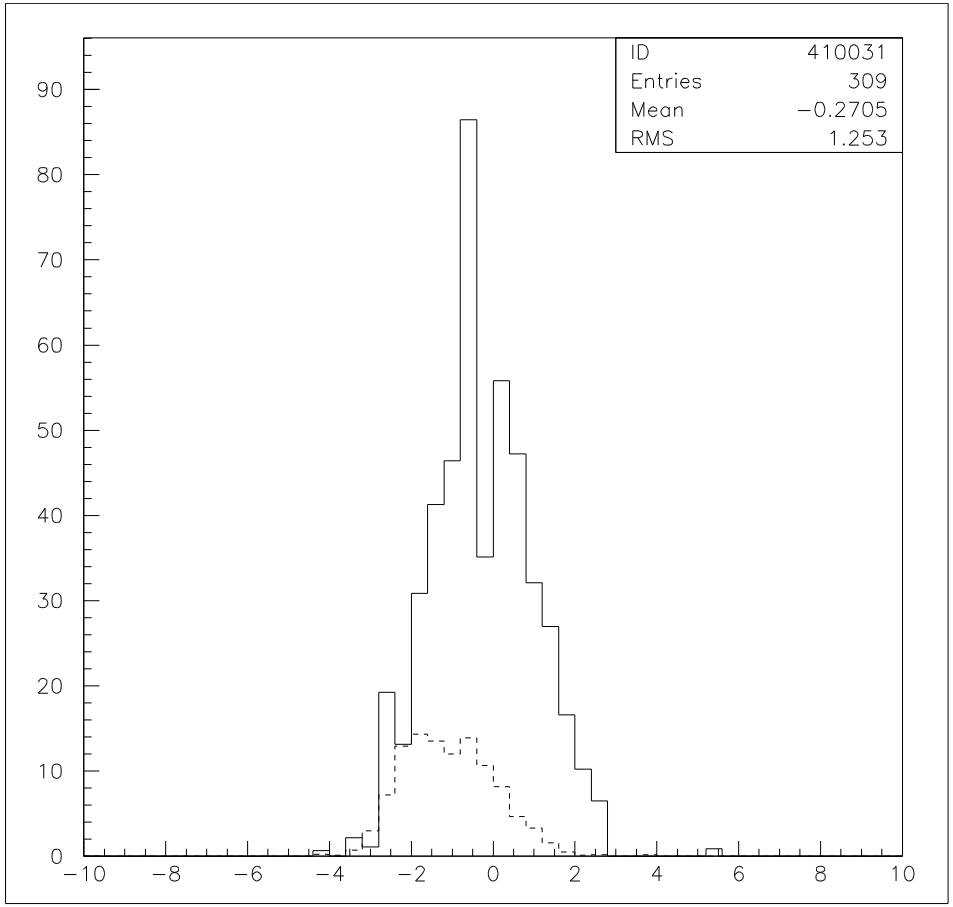
- Δ likelihood cut as a function of energy?

1.5<Erec<2.0 GeV



Δ likelihood

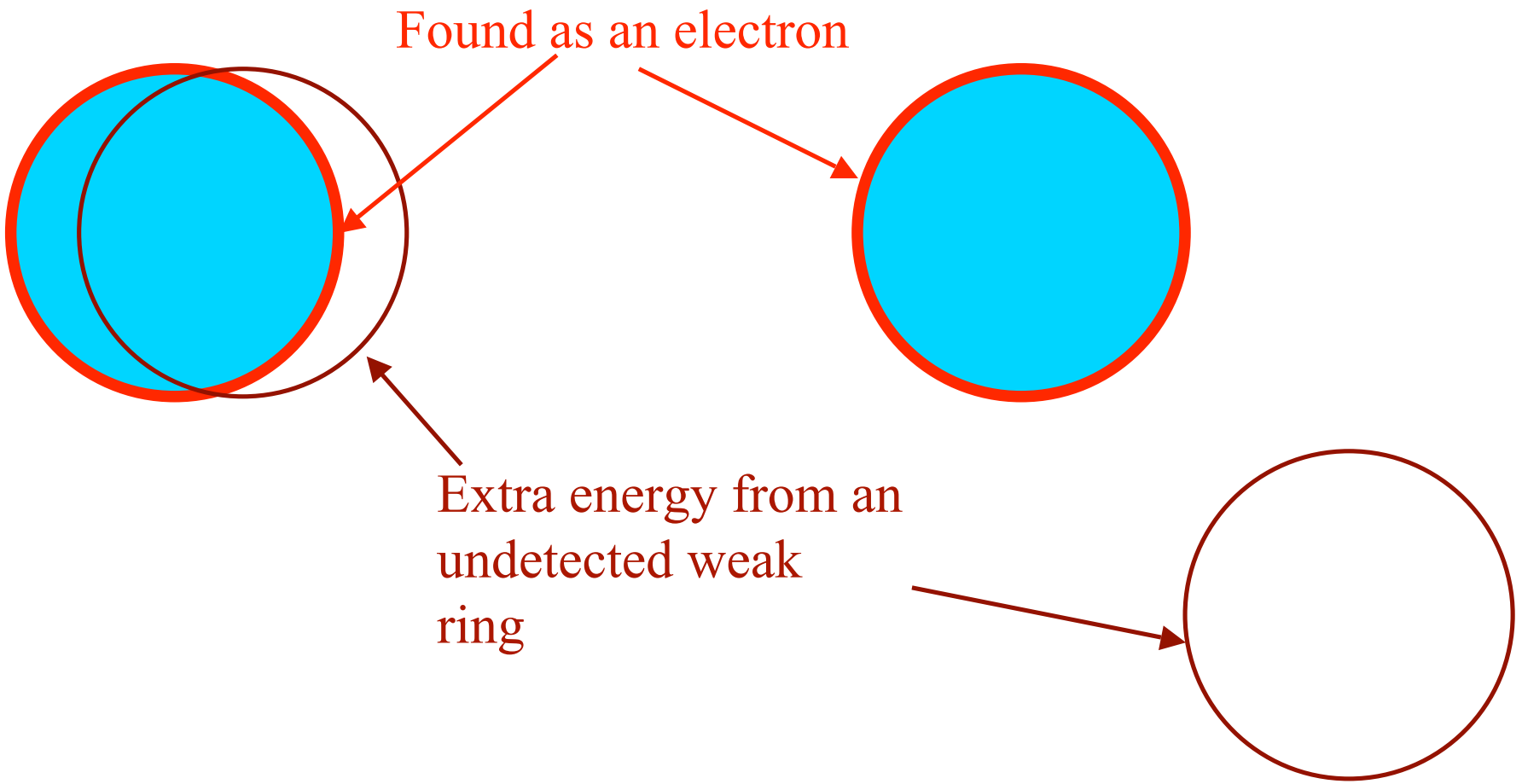
2.0<Erec<3.0 GeV



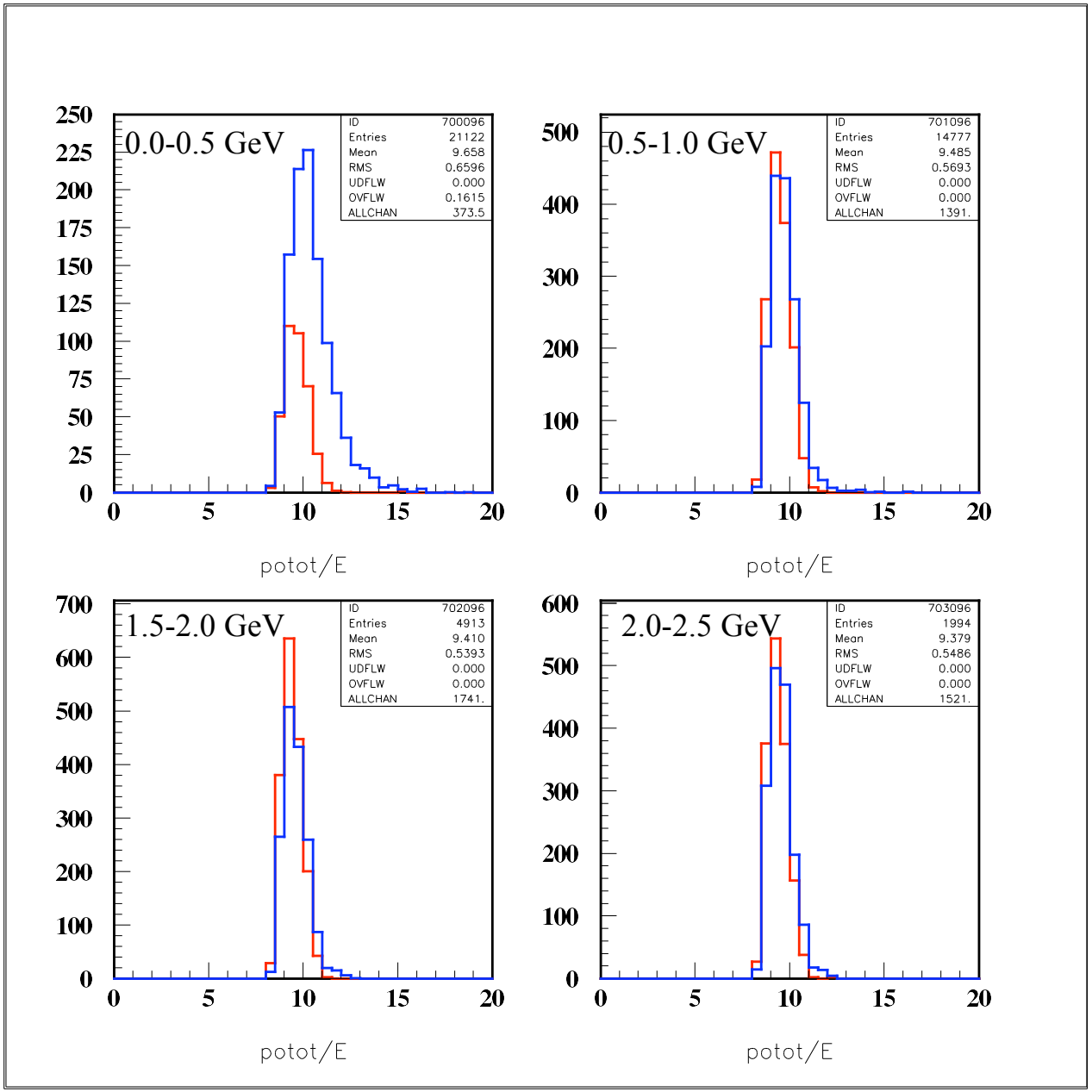
Δ likelihood

Introduction of new variables

- Total charge/electron energy (poa)



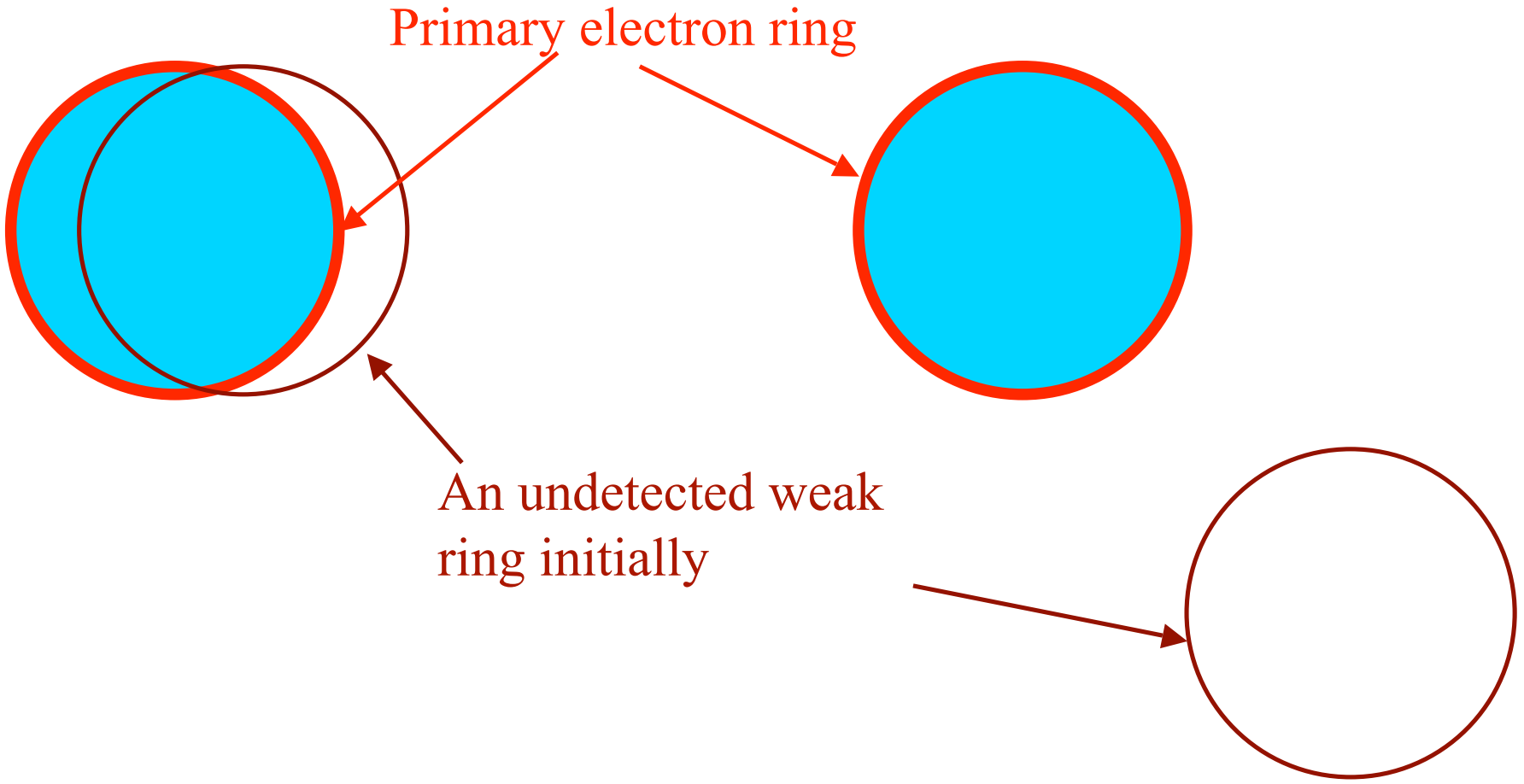
Total charge/electron energy (poa)



Introduction of new variables

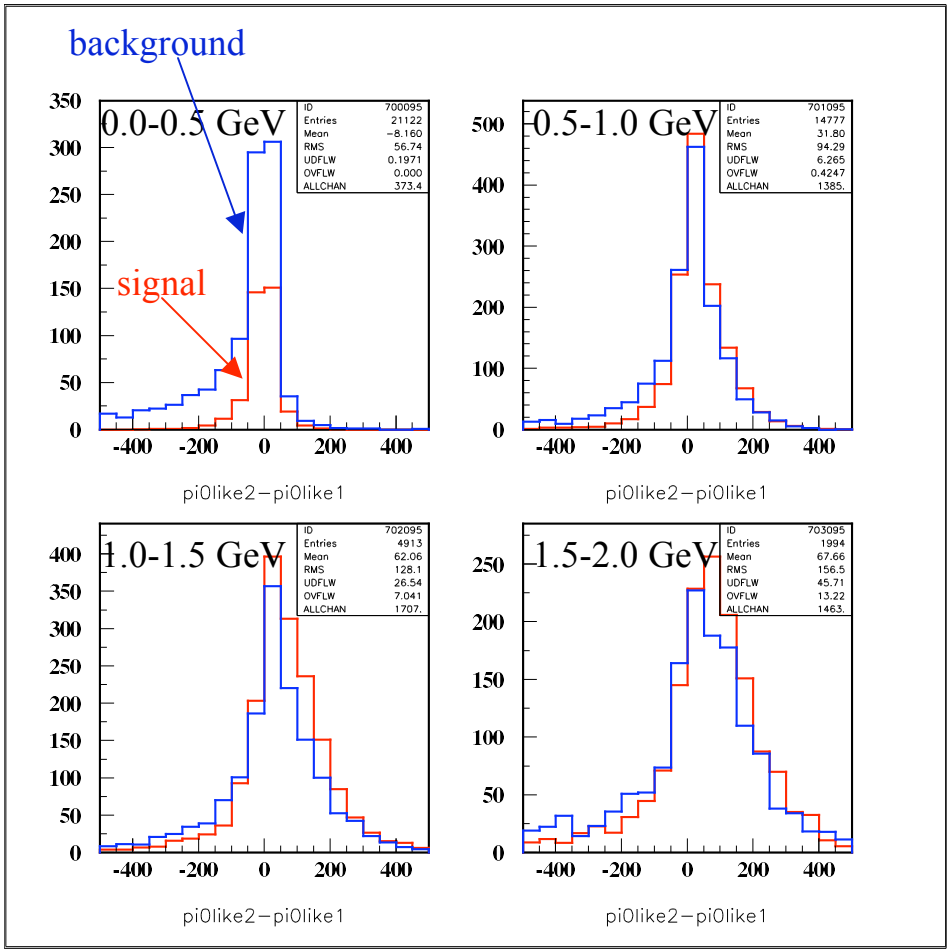
Difference in two pi0likelihoods

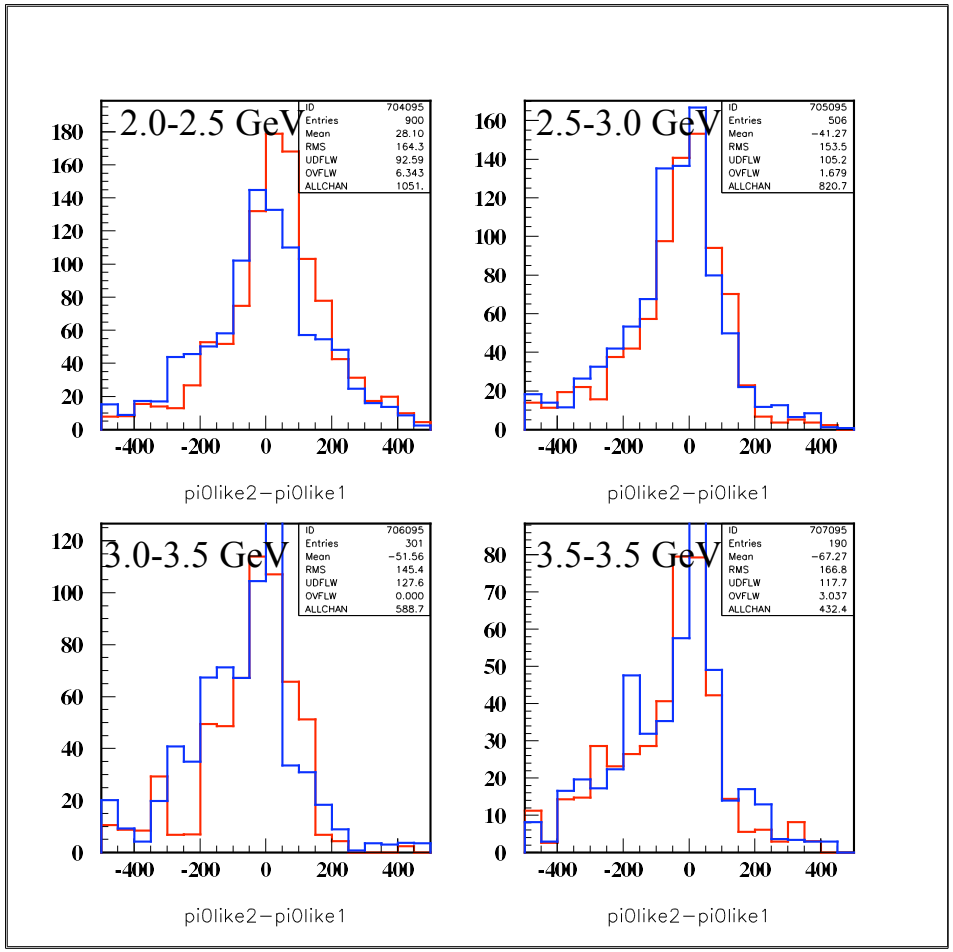
- One algorithm optimized to find extra ring near the primary ring (forward region)
- Another algorithm optimized to find extra ring in wider space (wide region)
- See the difference pi0lh(fowrad)-pi0lh(wide)



Introductions of new variables

- Difference in two pi0likelihoods

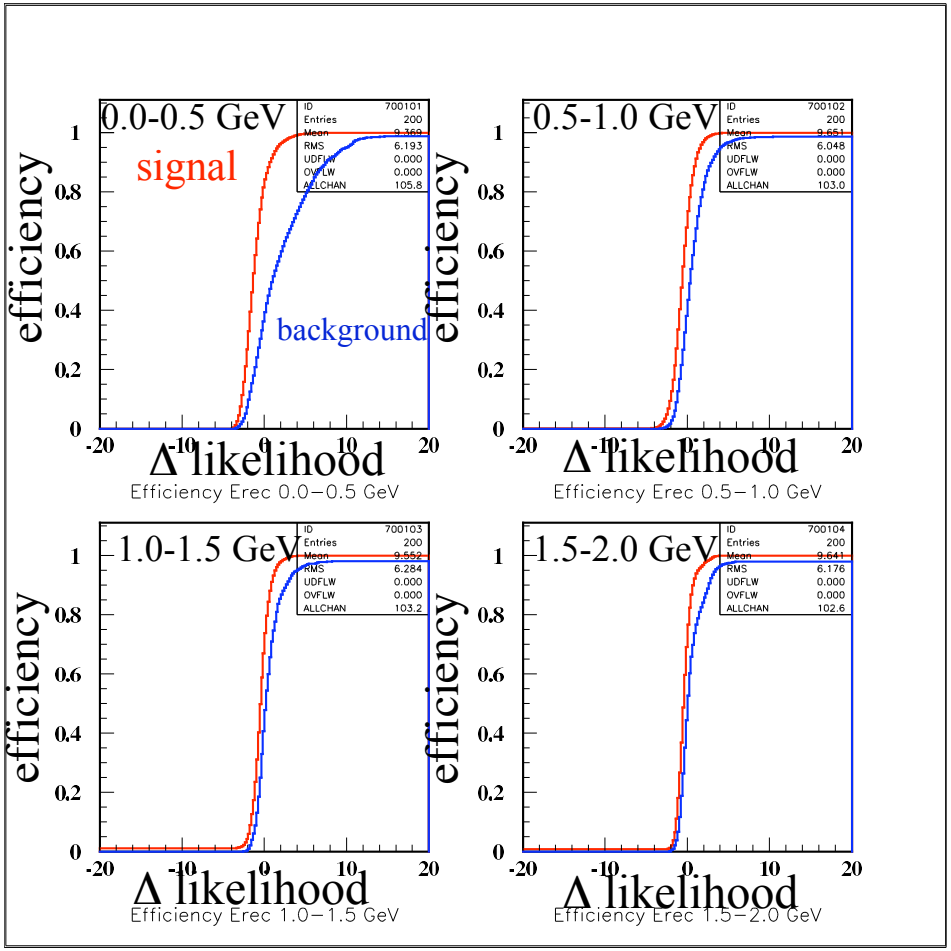


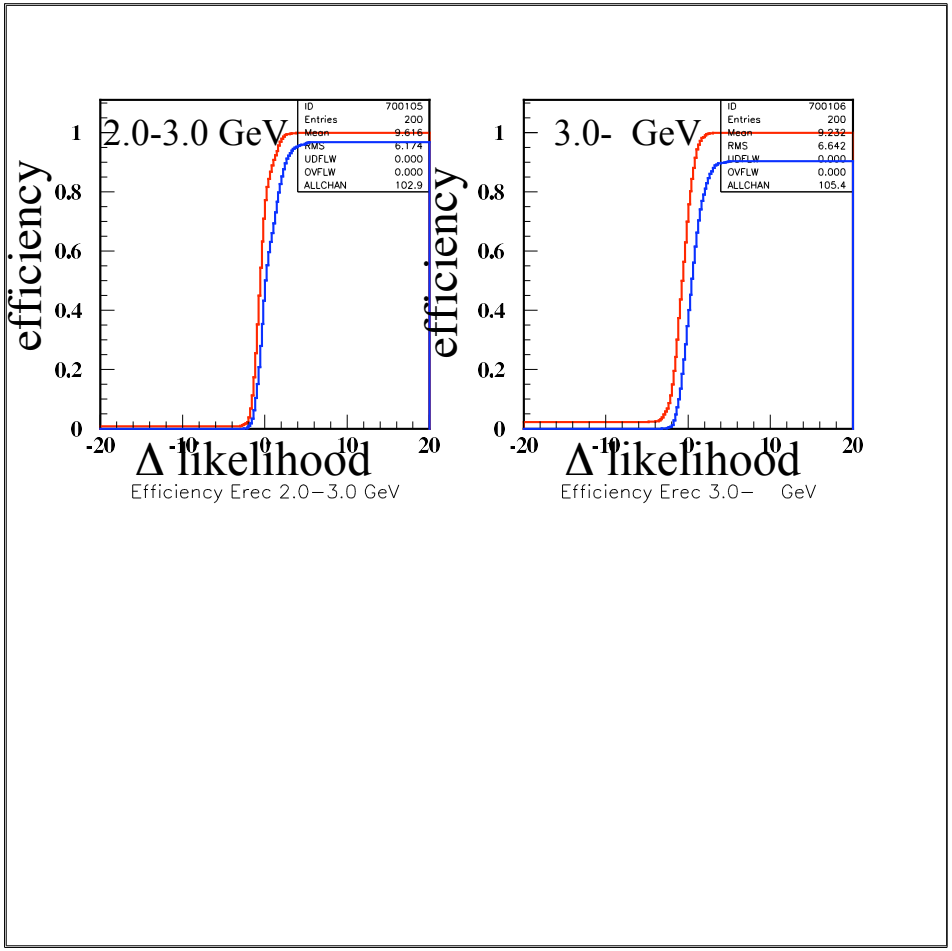


New Analysis

Efficiency

- Effect of cut on Δ likelihood





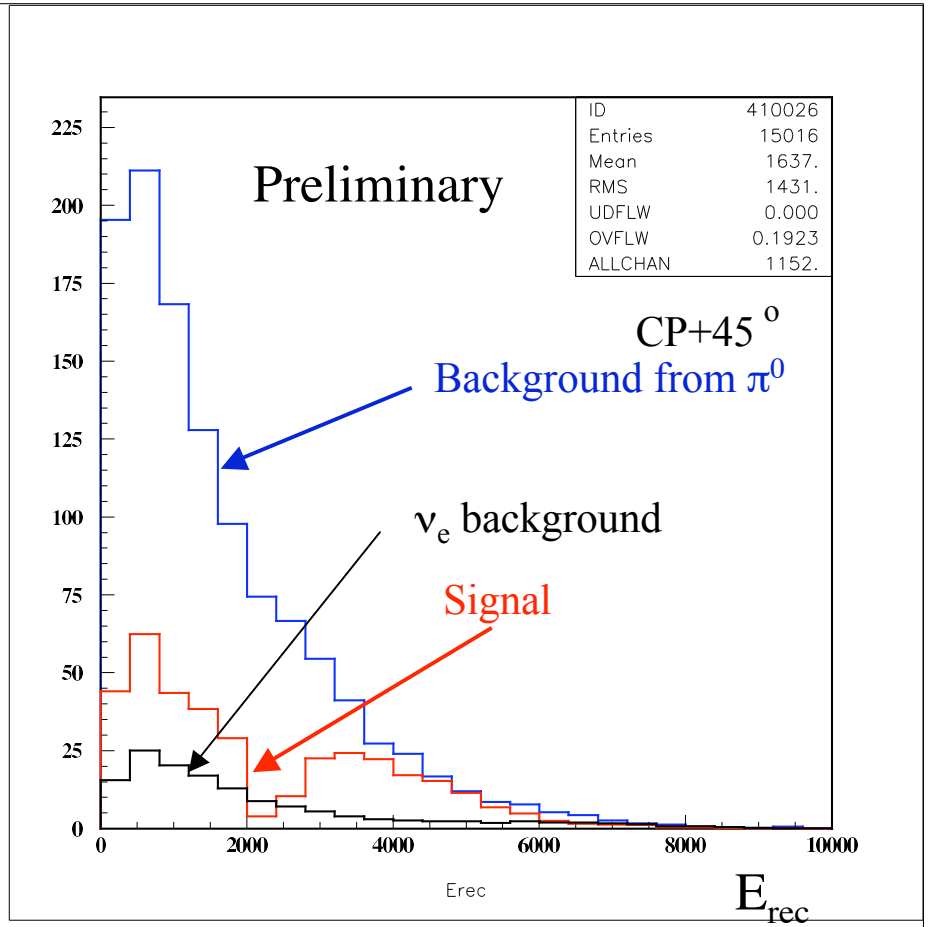
Note new background estimate!

New Analysis

Singnal and Background ν_e QE for signal, all ν_μ and ν_e NC/nonQE CC for bkg

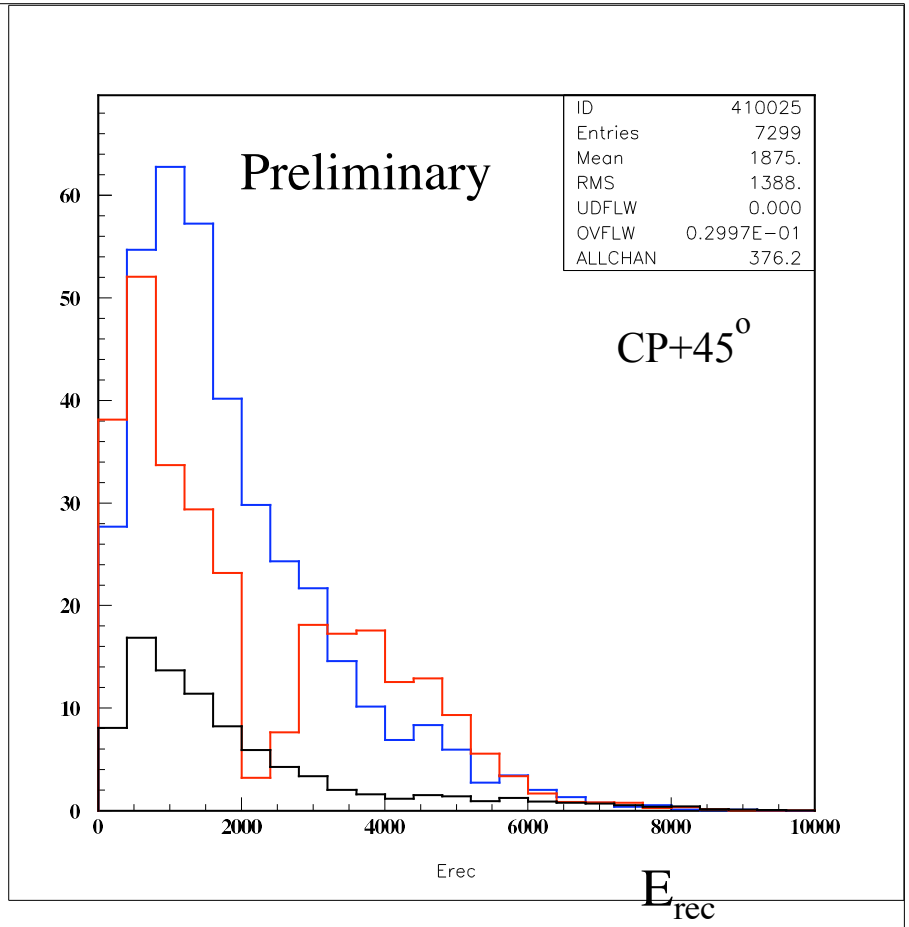
- Effect of cut on Δ likelihood

No Δlikelihood cut (~100% signal retained)



Signal 365 ev Bkgs 1293
(1152 from π^0+others)
(141 from ν_e)

Δlikelihood cut (~80% signal retained)



Signal 289 ev Bkgs 463
(376 from π^0+others)
(86 from ν_e)

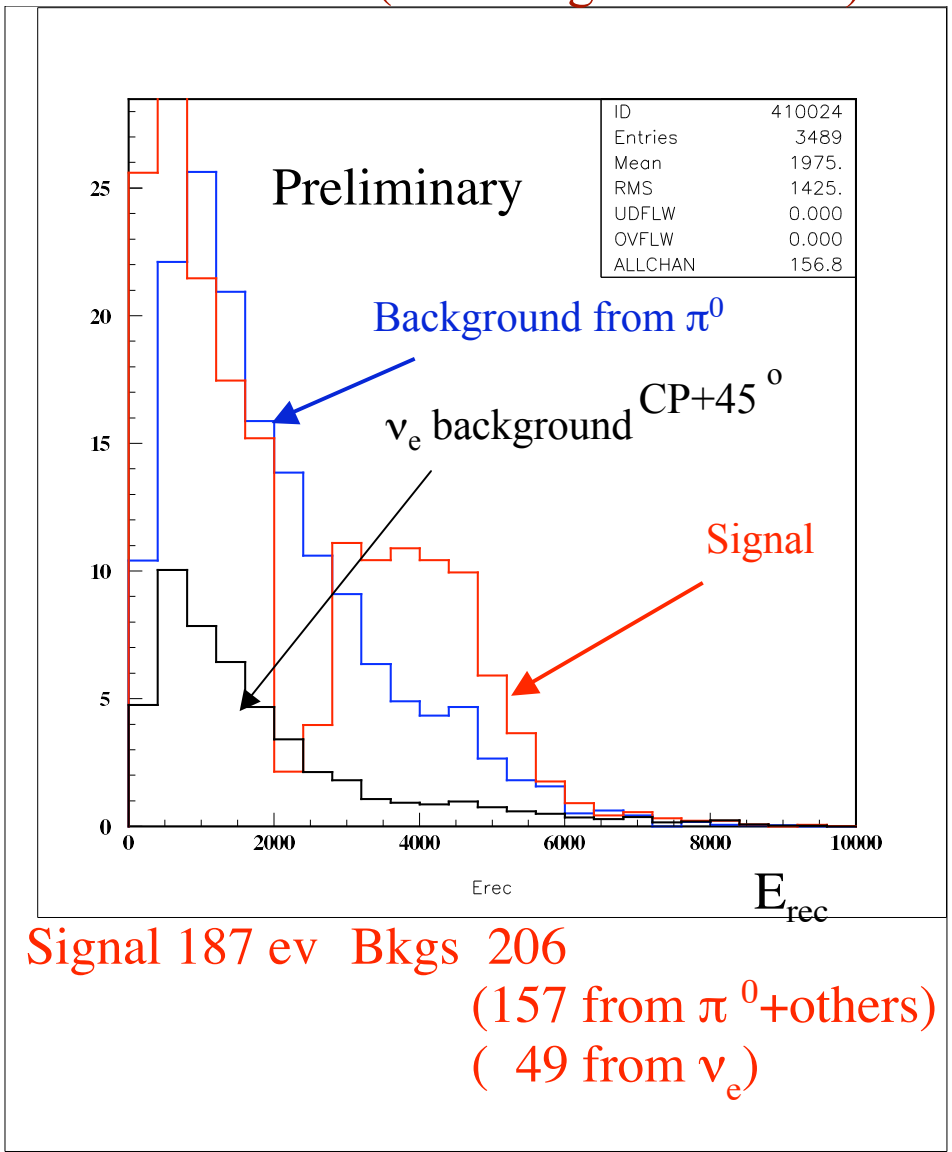
Note new background estimate!

New Analysis

Singnal and Background ν_e QE for signal, all ν_μ and ν_e NC/nonQE CC for bkg

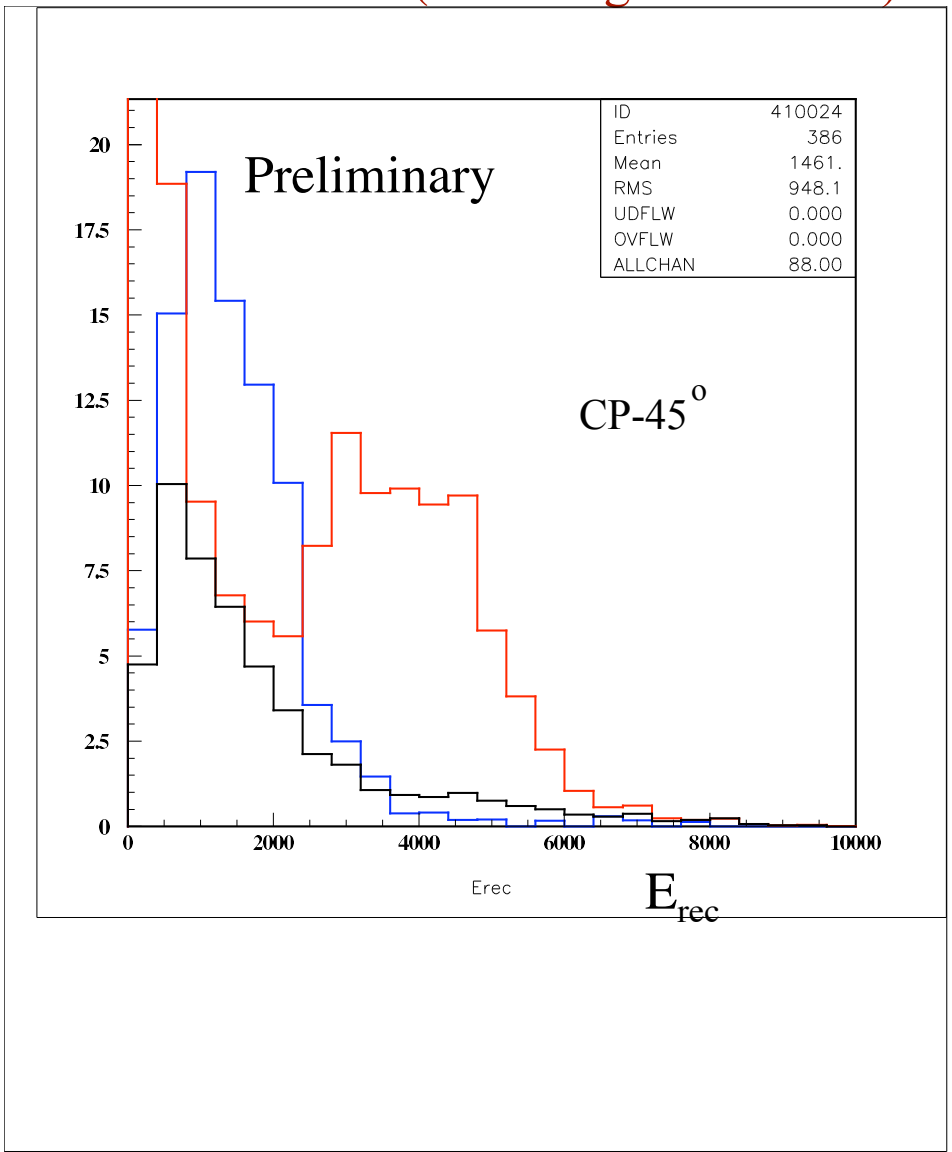
- Effect of cut on Δ likelihood

Δlikelihood cut (~50% signal retained)



Signal 187 ev Bkgs 206
(157 from π 0+others)
(49 from ν_e)

Δlikelihood cut (~50% signal retained)



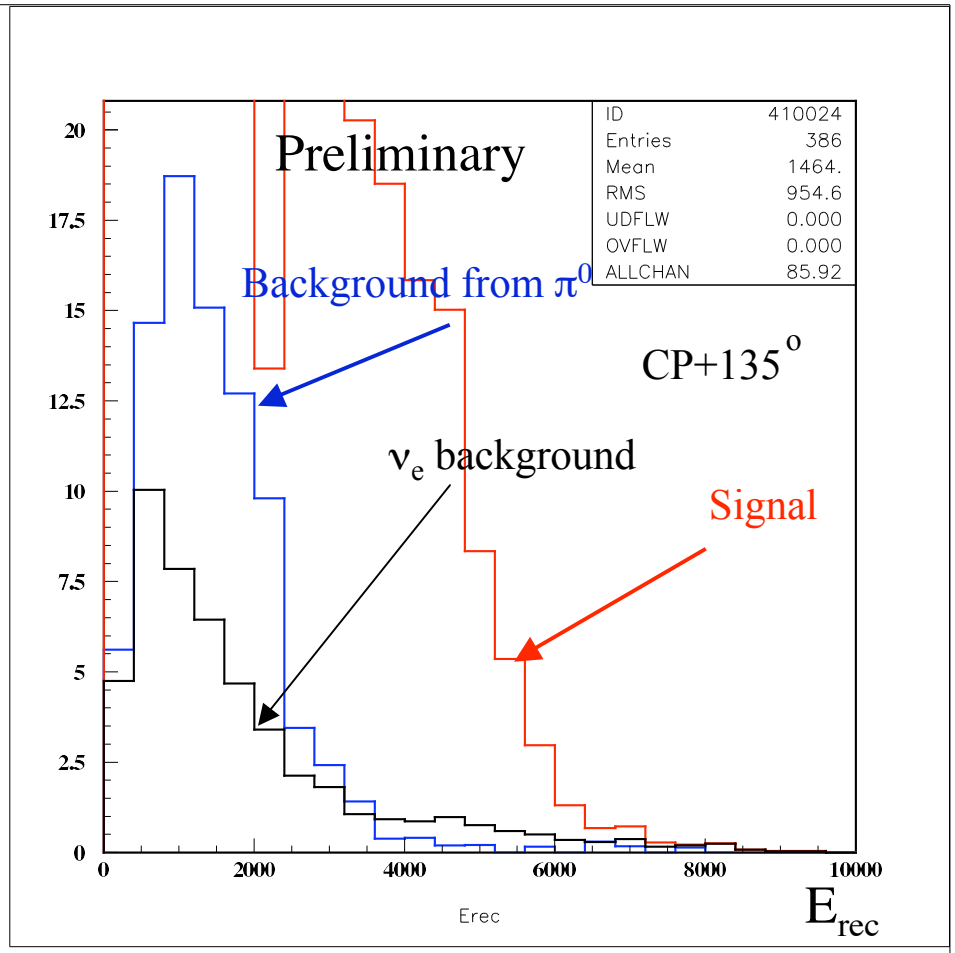
Note new background estimate!

New Analysis

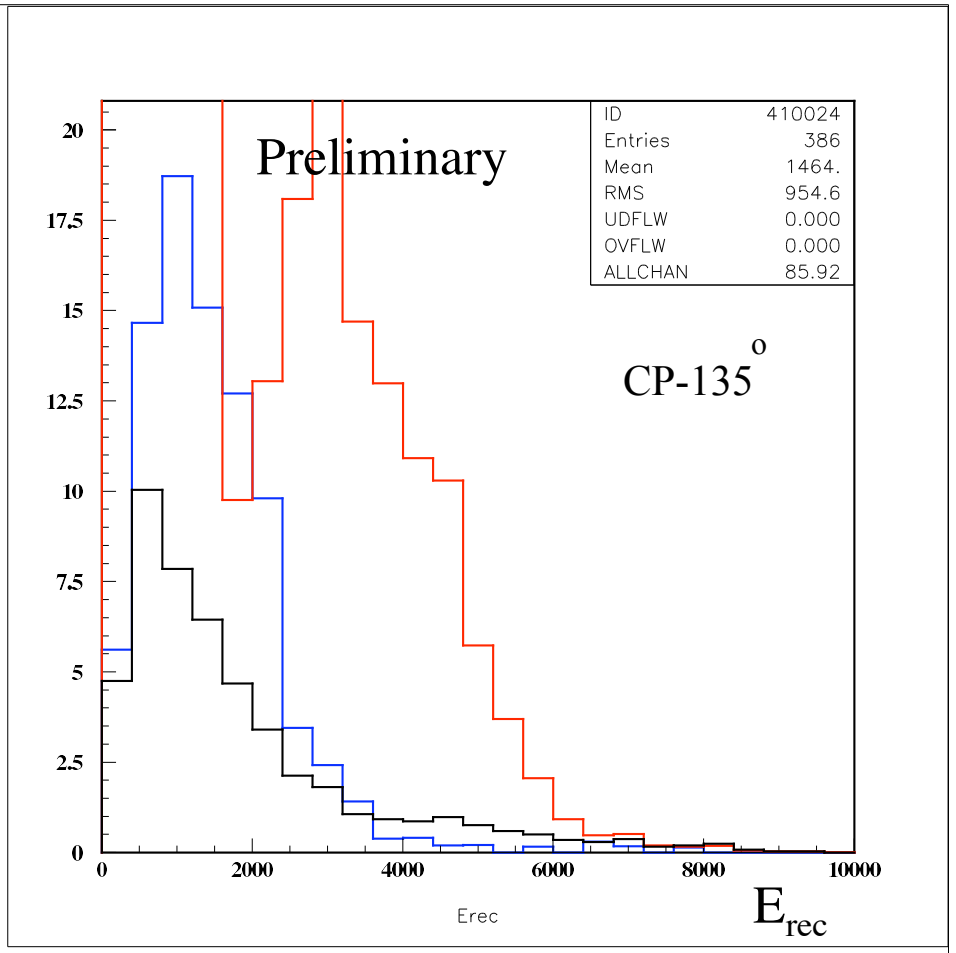
Singnal and Background ν_e QE for signal, all ν_μ and ν_e NC/nonQE CC for bkg

- Effect of cut on likelihood

Δlikelihood cut (~50% signal retained)



Δlikelihood cut (~50% signal retained)



_ S/N issue

NEW background estimation!

Summary of BNL superbeam@UNO

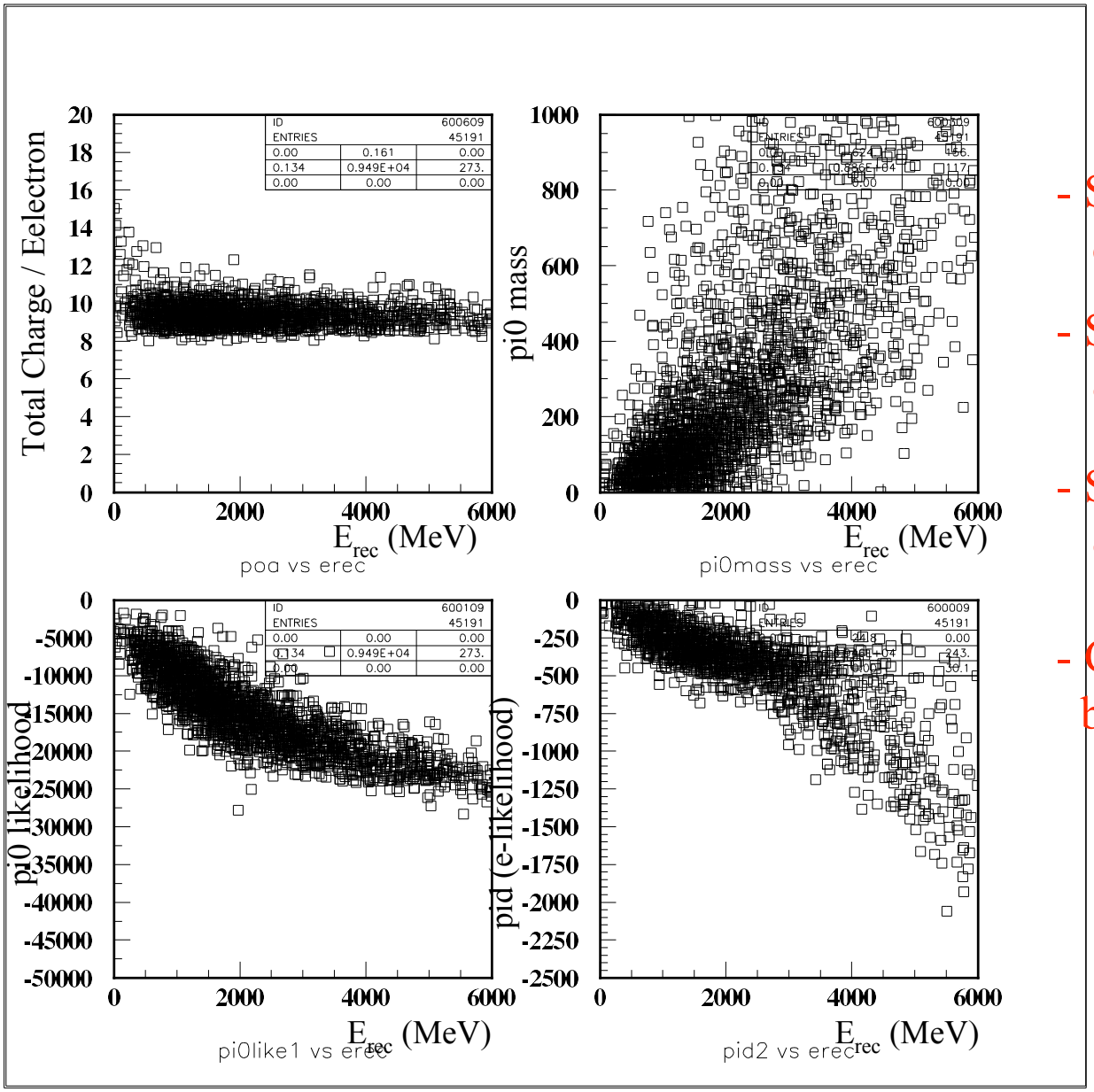
CP phase	Signal	Bkg	Effic	Signal	Bkg	Beam ν_e
0°	ν_e QE	ν_μ all, ν_e NC/nonQECC	50%	130 179	137 88	49
-135°	ν_e QE	ν_μ all, ν_e NC/nonQECC	50%	174 240	151 86	49
+135°	ν_e QE	ν_μ all, ν_e NC/nonQECC	50%	258 353	181 86	49
-45°	ν_e QE	ν_μ all, ν_e NC/nonQECC	50%	103 142	127 86	49
+45°	ν_e QE	ν_μ all, ν_e NC/nonQECC	100%	365 689	1152 834	141 141
			80%	289 439	376 227	86 86
	ν_e CC	ν_μ all, ν_e NC	50%	187 256	157 88	49 49

We are really in business!

Correlations

Correlations with E_{rec}

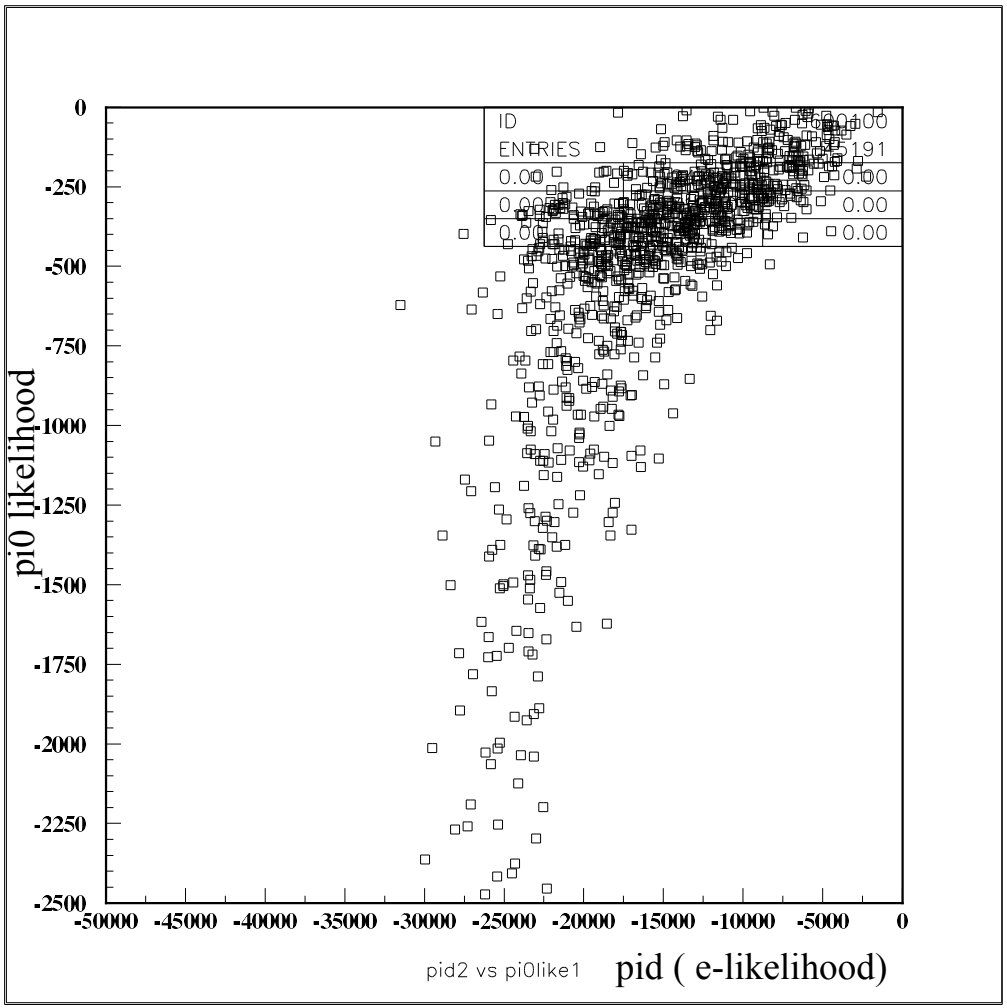
Source of energy dependence of likelihood



- Some variables are independent of energy
- Some variables have positive correlation with energy
- Some variables have negative correlation with energy
- Correlations with energy may bring correlations among variables

Correlations

- Correlations among variables used for likelihood



Future prospect

- Number of variables used needs to be reduced

- Correlations may have to be reduced as much as possible or properly treated

Some special technique to be employed such as Principal Component Analysis(?)

- Some variables associated with some pattern recognition such as pi0-likelihood and e-likelihood seem quite useful

More sophisticated pattern recognition algorithm is highly desirable and possible

- This kind of analysis can give an insight to optimize neutrino beam spectrum

Studies on sensitivities to oscillation parameters should be done

Careful study of the source of background and the associated neutrino energy is needed

Conclusions

- Realistic MC simulation studies have been performed for BNL very long baseline with a water Cherenkov detector and it was found that BNL VLBL combined with UNO can do great job

- It was demonstrated that there is some room to improve SN ratio by reducing the background level while keeping a reasonable signal detection effciency with current available software

  - A strong suppression in low energy region has gone away while retaining a similar S/N ratio A big improvement!

  - Further improvement of algorithm/software is essential and possible

  - Detailed studies on sensitivity on oscillation parameters needed

  - A larger detector such as UNO has an advantage over a smaller detector such as SK (See my talk in Minneapolis, April,2004)

Need a detailed Monte Carlo package for UNO!